Analysis of Sub-Mesoscale Features in Indonesian Seas

R. Dwi Susanto
Lamont-Doherty Earth Observatory of
Columbia University
61 Route 9W, Palisades, NY 10964
Phone: 845-365-8545 fax: 845-365-8157 e-mail: dwi@ldeo.columbia.edu

Award Number: N00014-04-1-0698

LONG-TERM GOALS

The long-term goal of this research is to understand and to establish the importance of various physical drivers for the sub-mesoscale generation mechanism, dynamics, evolution and propagation in the Indonesian seas.

OBJECTIVES

The proposed research will focus on the analyses of sub-mesoscale features in the major straits of Indonesian throughflow pathways (Makassar, Lombok and Ombai Straits, Timor and Lifamatola passages). The main objectives are to describe the general features and analyze generation mechanism, evolution, propagation of sub-mesoscale ocean features; and to establish the relative importance of various physical drivers for the sub-mesoscale generation, evolution, propagation, and their variability, and to identify and quantify the underlying physical and dynamical processes affecting their variability.

APPROACH

In this research, the PI use both *in situ* and remotely sensed data. Historical *in situ* data are gathered from the various cruises of the Indonesian throughflow program (Murray and Arief, 1988; Murray et al., 1990; Ffield and Gordon, 1996; Chong *et al*. 2000; Hautala *et al*., 2001; Gordon and Susanto, 2003; Susanto and Gordon, 2005) as well as on-going field measurement from the INSTANT (International Nusantara Stratification and Transport) program (Sprintall *et al*., 2004). For the remotely sensed data, the main source is the synthetic aperture radar (SAR) carried by various satellites, i.e., ERS-1/2, Radarsat-1/2 and Envisat. High resolution NOAA AVHRR data and SeaWifs, as well as data from Terra and Aqua satellites will also be used. For the analysis, for different features the PI plans to apply different data analysis methods, which best match the nature of these features i.e. wavelet transform, Hilbert Huang Transform, regression analysis, and Empirical orthogonal function.

WORK COMPLETED

More than hundreds quick-look SAR images have been obtained from various sources: i.e. The Center for Remote Imaging, Sensing and Processing, National University of Singapore, European Space Agency (ESA), and Radarsat. Analysis and interpretation of these images in combination with historical hydrographic data as well shallow pressure gauge array data in the Lombok Strait has been

Report Documentation Page

Form Approved
OMB No. 0704-0188

Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

1. REPORT DATE **30 SEP 2006**	2. REPORT TYPE	3. DATES COVERED **00-00-2006 to 00-00-2006**
4. TITLE AND SUBTITLE **Analysis of Sub-Mesoscale Features in Indonesian Seas**		5a. CONTRACT NUMBER
		5b. GRANT NUMBER
		5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER
		5e. TASK NUMBER
		5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Lamont-Doherty Earth Observatory of Columbia University,61 Route 9W,Palisades,NY,10964**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR’S ACRONYM(S)
		11. SPONSOR/MONITOR’S REPORT NUMBER(S)
12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release; distribution unlimited**		
13. SUPPLEMENTARY NOTES		
14. ABSTRACT		
15. SUBJECT TERMS		

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**6**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

done. A manuscript (Susanto et al., 2005) on the internal wave characteristics in the Lombok Strait was published in *Oceanography*. Additional manuscript is being prepared.

Combination analysis of historical *in situ* data (XBT, CTD, moorings data) and remotely sensed data (SST, winds, Chlorophyll-a) over the Indonesian region has been done. Three papers have been published: *Susanto et al.* (2006) in *Geochemistry Geophysics and Geosystems* and *Susanto and Marra (2005) in Oceanography* and one manuscript (Susanto et al.,2006) is on review, in *Journal Geophysical Research-Oceans.* Analysis on interaction between South China Sea and Indonesian Seas (Fang et al., 2005) has been published in *Advances in Atmospheric Science.*

RESULTS

Because of complex coastline geometry and bathymetry, stratified water and strong tidal current Indonesian Seas are a favorable place for sub-mesoscale features generation such as internal waves, fronts and jets. Tidal conditions, Indonesian throughflow variability, and stratification control generation and propagation directions of the internal waves in the Lombok Strait. The internal wave dynamical parameters: the wavelength, number of solitons in a packet, characteristic half width, propagation direction, and phase speed are determined from both *in situ* and remotely sensed data. Depending on the tidal conditions and the throughflow variability, internal waves in the Lombok Straits could either propagate northward only, southward only or both directions. Figure 1 shows bathymetry of the Lombok Strait, internal waves observed from SAR, and tidal conditions at the time the images were taken. Figure 2 shows in situ observation during the INSTANT cruise in the Lombok Strait in 2005 when internal waves were observed using (a) regular camera of sea surface conditions (b) sonar onboard of the ship and (c) onboard echosounder.

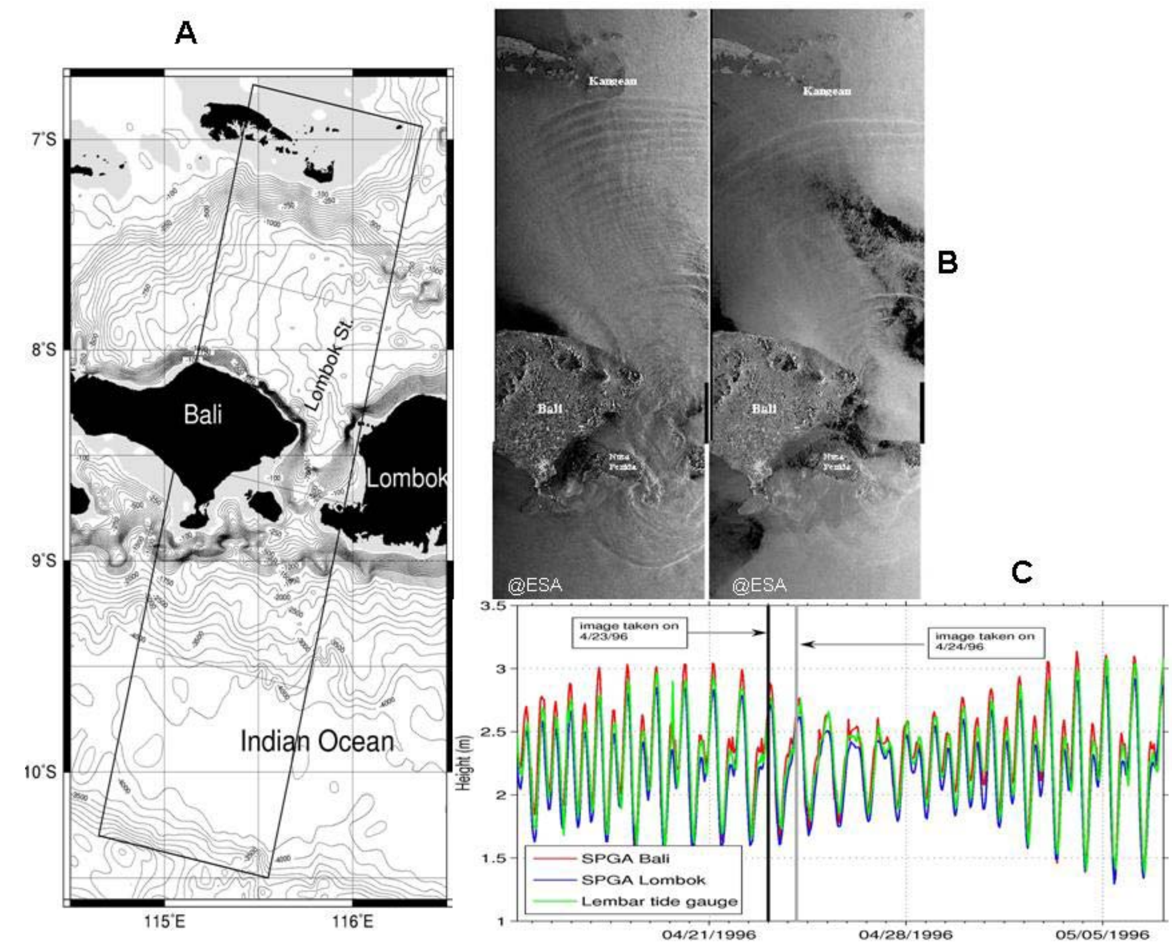
Analysis of in situ data (XBT, CTD, moorings) and remotely sensed data (SST from NOAA-AVHRR, chlorophyl-a from SeaWifs and Modis, winds from scatterometers, sea level from TOPEX/Poseidon and Jason-1 altimeters) over Indonesian region indicates that dynamics of Indonesian Seas strongly affected by monsoon and ENSO. Upwelling occurs during the southeast monsoon (April-October) along the southern coasts of Sumatra-Java and Nusa Tenggara (east-west series of islands from Lombok to Timor) and eastern Banda Sea. ENSO modulates the upwelling; during El Nino events, upwelling is stronger, cooler SST, shallower thermocline, lower sea level and higher chlorophyll-a concentration. Figure 3 shows SST and chlorophyll-a concentration during (a) the peak of northwest (February) monsoon and (b) southeast (August) monsoon and (c) during the peak of 1997/98 El Nino event.

IMPACT/IMPLICATIONS

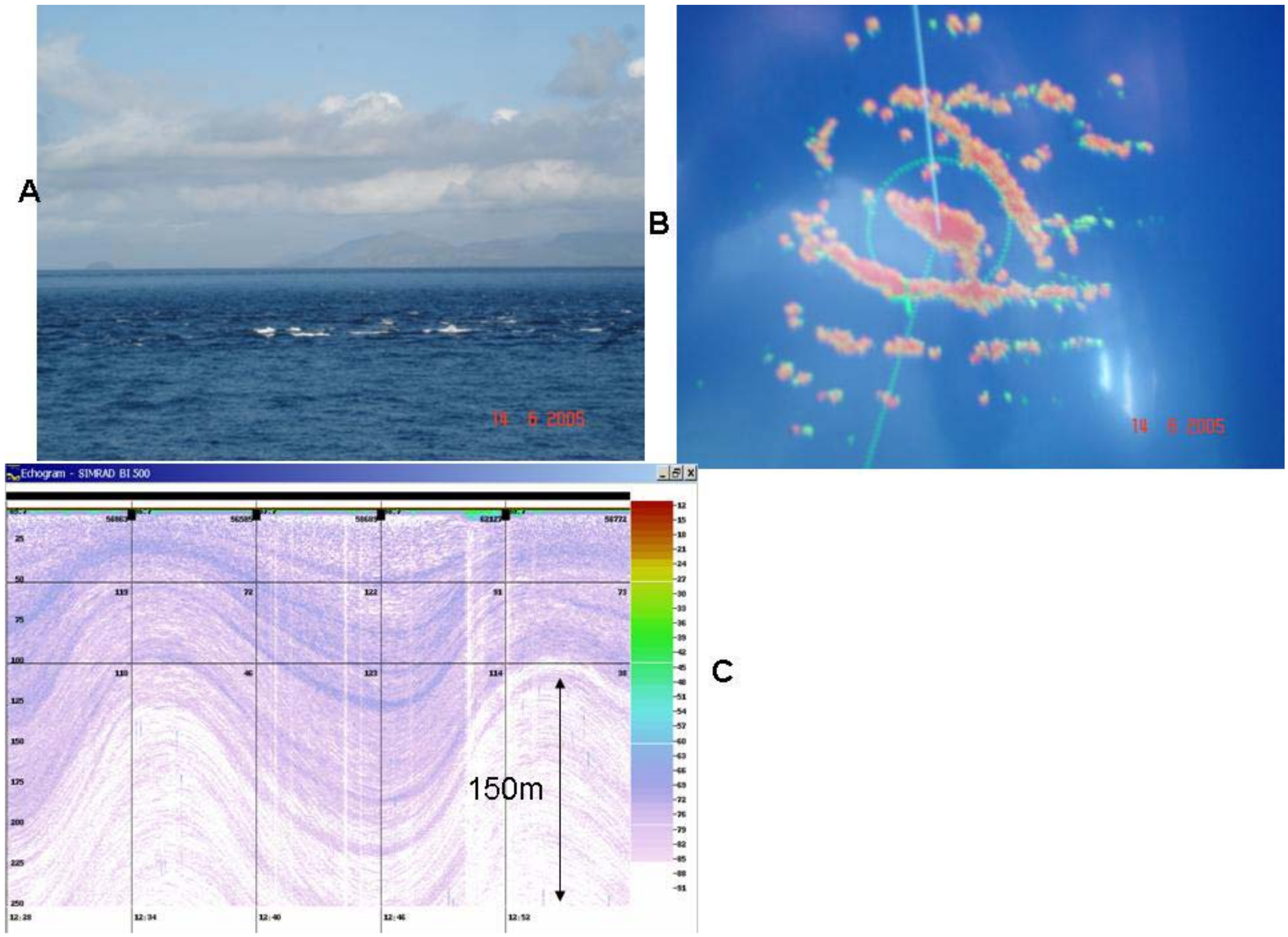
Major inflow and outflow straits of the Indonesian throughflow where sub-mesoscale may generated, are also the main routes for shipping from the Pacific to Indian Oceans and these sub-mesoscale features affect acoustic signals, therefore, flow pattern and sub-mesoscale feature studies in these straits not only an important component for understanding upper ocean dynamics but also for industrial, marine safety, and military uses. In addition, these the throughflow and sub-mesoscale features affect the chlorophyll-a concentration.

RELATED PROJECT

There is an ongoing international [Indonesia, United States, Australia, France, and the Netherlands] collaborative research called INSTANT. The US part supported by NSF. The primary objective of INSTANT is to measure the variability of the ITF and its associated heat and freshwater flux exported into the Indian Ocean. INSTANT PI's have deployed 11 moorings in major inflow passages from the Pacific Ocean (Makassar Strait & Lifamatola Passage) and outflow passages to the Indian Ocean (Lombok and Ombai Straits, and Timor passage; Gordon, 2004; Sprintall *et al.*, 2004). Turn around deployment conducted on June-July 2005 and the data are being processed. The final recovery is being plan for November-December 2006.



[Figure 1. (a) Bathymetry of the Lombok Strait, (b) internal waves observed from SAR, and (c) tidal conditions at the time the images were taken (Susanto et al., 2005)]



[Figure 2. Internal waves observed in the Lombok Strait during the INSTANT cruise in 2005, observed using (a) regular camera of sea surface conditions (b) sonar onboard of the ship and (c) onboard echosounder. The wave amplitude is ~150m (Susanto et al., 2005)].

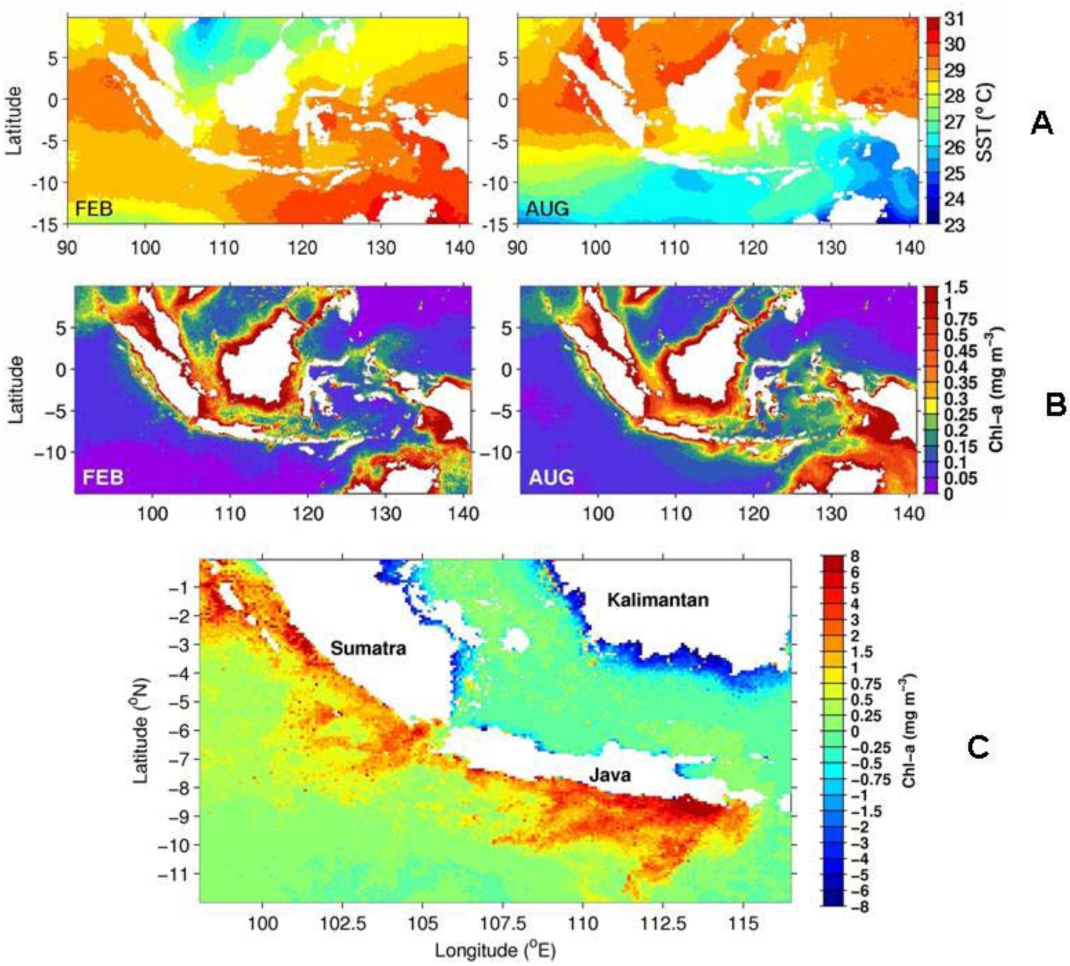


Figure 3. SST and chlorophyll-a concentration during (a) the peak of northwest (February) monsoon and (b) southeast (August) monsoon and (c) during the peak of 1997/98 El Nino event. Susanto and Marra, 2005; Susanto et al., 2006]

REFERENCES

Chong, J., J. Sprintall, S. Hautala, W. Morawitz, N. Bray, and W. Pandoe (2000) Shallow throughflow variability in the outflow straits of Indonesia, *Geophys. Res. Letts*. 27, 125-128.

Ffield, A., and A.L. Gordon (1996) Tidal Mixing Signatures in the Indonesian Seas, *J. Phys. Oceanogr.*, 26, 1924-1937.

Gordon A.L. (2004), International Nusantara Stratification Program (INSTANT), *Proceeding of* the 1st *CLIVAR International Workshop*, Baltimore.

Gordon, A. L., R. D. Susanto, and K. Vranes (2003) Cool Indonesian Throughflow is a Consequence of Restricted Surface Layer Flow, *Nature*, 425, 824-828.

Murray, S.P., and D. Arief (1988) Throughflow into the Indian Ocean through Lombok Strait, January 1985-January 1986, *Nature*, 333, 444-447.

Murray, S.P., D. Arief, J.C. Kindle, H.E. Hulburt (1990) Characteristics of circulation in an Indonesian archipelago strait from hydrography, currents measurements and numerical model results, *The Physical Oceanography of Straits,* L. J. Pratt, (Ed.), 3-23, Kluwer Academic Publishers, Norwell, Massachusetts.

Sprintall, J., S. Wijffels, A. L. Gordon, A.Ffield, R. Molcard, R. D. Susanto, I. Soesilo, J. Sopaheluwakan, H. M. van Aken (2004) A New International Array to Measure the Indonesian Throughflow: INSTANT, *EOS*.

Susanto, R.D., A.L Gordon, J. Sprintall, and B. Herunadi (2000) Intraseasonal variability and tides in Makassar Strait, *Geophys. Res. Lett.*, 27, 1499-1502.

Susanto, R.D. and A.L.Gordon, Velocity and transport of Indonesian throughflow in Makassar Strait,

J. Geophys. Res., 100, C1, 2005.

PUBLICATIONS

Susanto, R.D., Q. Zheng, L. Mitnik, and J. Sprintall, Statistical and dynamical analysis of internal waves in the Lombok Strait, [in Preparation].

Susanto, R. D., L. Mitnik and Q. Zheng, Ocean internal waves observed in the Lombok Strait, *Oceanography*, 18,4, 80-87, 2005

Susanto, R.D., T. Moore II and J. Marra, An ocean color variability in the Indonesian Seas during the SeaWifs Era, *Geochemistry Geophysics Geosystems*, 7, 5 doi:10.1029/2005GC001009, 1-16, 2006

Fang, G, R.D. Susanto, I. Soesilo, Q. Zheng, F. Qiao and Z. Wei, Notes on the upper-layer interocean circulation of the South China Sea, *Advances in Atmospheric Sciences COAA Special Issue*, 22, 6, 946-954, 2005.

Zheng, Q., R. D. Susanto, C-R. Ho, Y. T. Song, and Q. Xu, Statistical and dynamical analyses of generation mechanisms of solitary internal waves in the northern South China Sea. *J. Geophys. Res.,* 2006 (in press).

Susanto, R. D., A. L. Gordon, and J. Sprintall, Observations and Proxies of the Surface Layer throughflow in Lombok Strait, *J. Geophys. Res.*, [in Review], 2006